Study into the definition of non-isolated Muon ID

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Introduction

The goal of the non-isolated muon ID is to define three sets of parameters that define three different qualities of muons:

- Tight: An object in the muon system, penetrating the toroid and is confirmed by a track in the central tracker
- Medium: An object in the muon system, penetrating the toroid but with either less muon hits than a tight muon, or lacking the confirmation of a track in the central tracker
- Loose: An object in the muon system, which can be:
    - A muon object on both sides of the toroid, but unconfirmed by a track in the central tracker, or
    - A muon object only in the A-layer, with the confirmation of a track in the central tracker, or
    - A muon object only in the BC-layer, with the confirmation of a track in the central tracker

Each of these requirements results in a cut on the properties of the track in the muon system, and the possible match with a track in the central tracker. Therefore, the following variables are used to determine these cuts:

- Number of wire hits in the A-layer
- Number of scintillator hits in the A-layer
- Total number of wire hits in the B+C layer
- Total number of scintillator hits in the B+C layer
- χ^2 of the muon track fit
- $\delta\varphi$ between the muon track and central track
- $\delta\eta$ between the muon track and central track
- Distance in drift direction (δz) between the muon track and the central track
- p_T relation between muon track and central track

To acquire the exact values for these variables that specify a certain quality of muon, a sample of real data is eye-scanned and divided in different qualities of muons. The properties listed above are investigated for each different quality, and preliminary cuts are defined. These cuts are then tested on MC data and real data.

Hand scanning real data

Events were selected from runs with run number 133007 through 133020, which were taken with the Global CalMuon1.5 trigger and reconstructed with version p10.07.01 of the d0reco reconstruction software. Two different samples were created:

- Sample 1: events with a reconstructed muon track segment in the A-layer, whereby the track is within $\delta R < 0.7$ of a jet[1], but the track is not matched with a segment in the B or C layer
- Sample 2: events with a reconstructed muon track with a segment before and after the toroid, within $\delta R < 0.7$ of a jet.

[1] In this study, a jet is defined as a jet reconstructed by the Run2 0.5 Cone algorithm

Both these samples were scanned using the d0ve event display. Events in sample 1 were subdivided in events with a loose muon (see figure 1), and events with no muons (see figure 2). Events in sample 2 were subdivided in events with a tight muon (see figure 3) and events with no tight (thus, medium, loose or none) muon. Note, that the central tracker information was not taken into account to determine whether a muon was tight, medium, loose or bad.

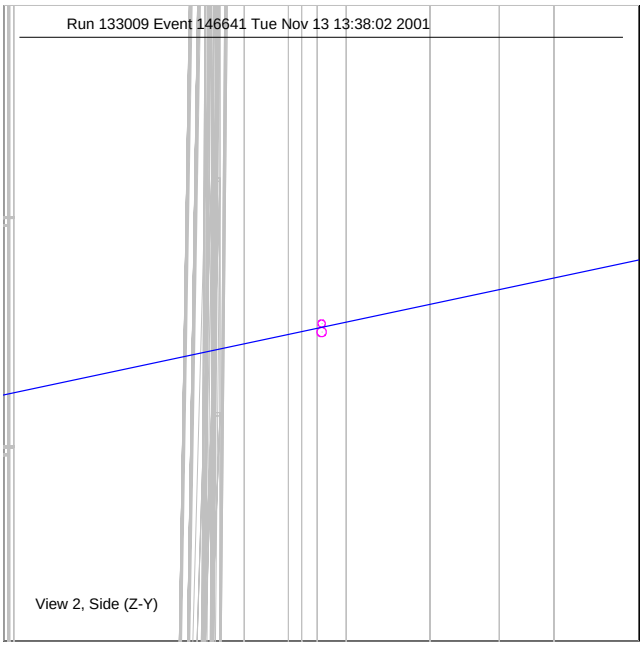

Figure 1: Muon segment with two wire hits and no scintillator hit in the A layer of the FAMUS. This muon does not pass the loose muon id criteria.

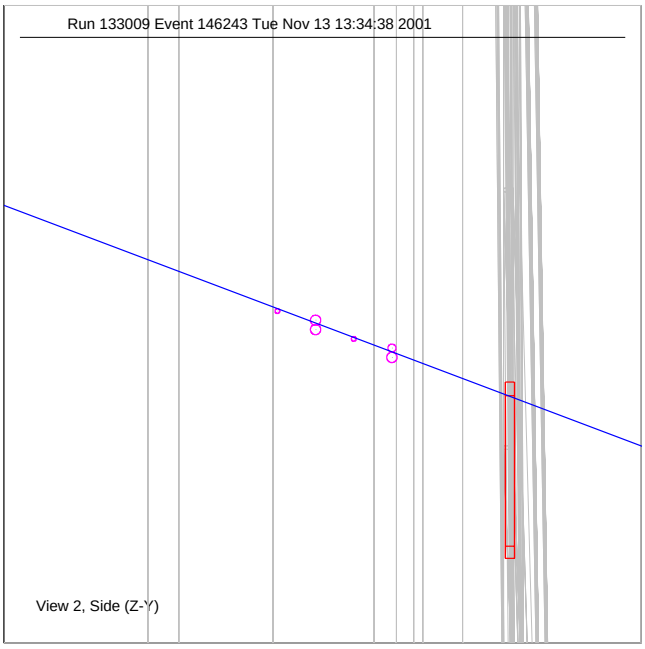

Figure 2: Muon segment with six wire hits and a scintillator hit in the A layer of the FAMUS. This muon passes the loose muon id criterion.

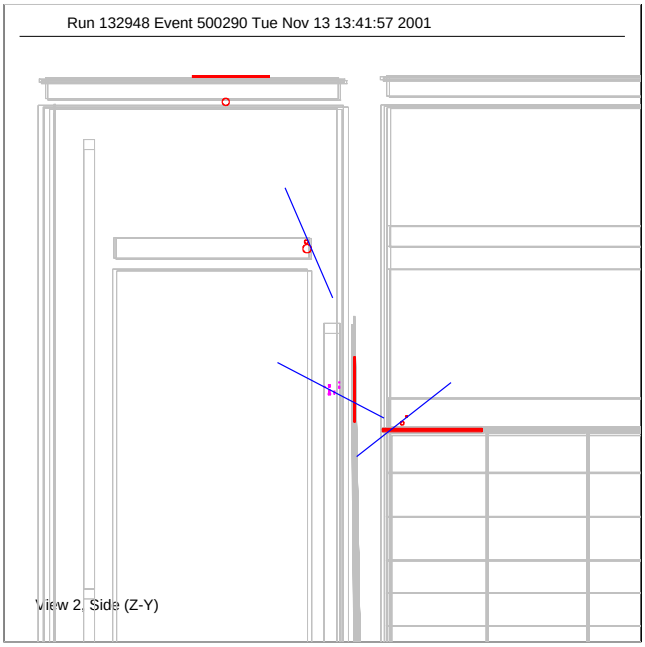

Figure 3: Muon object with three segments, not passing the tight or medium id criteria

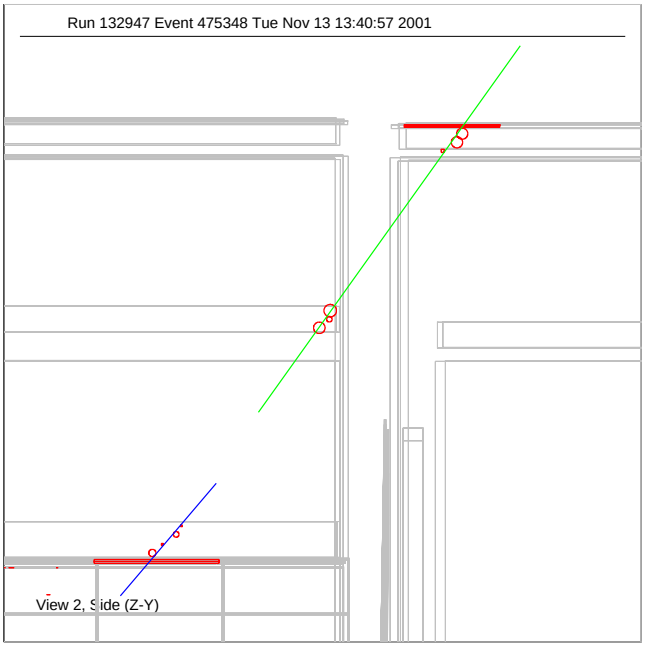

Figure 4: Muon object with three segments, passing the tight muon id criterion.

The number of hits for the Sample 1 is shown in Figure 5 for muon objects that have been defined as 'not passing the loose cut' and in Figure 6 for muon objects that have been defined as 'passing the loose cut'.

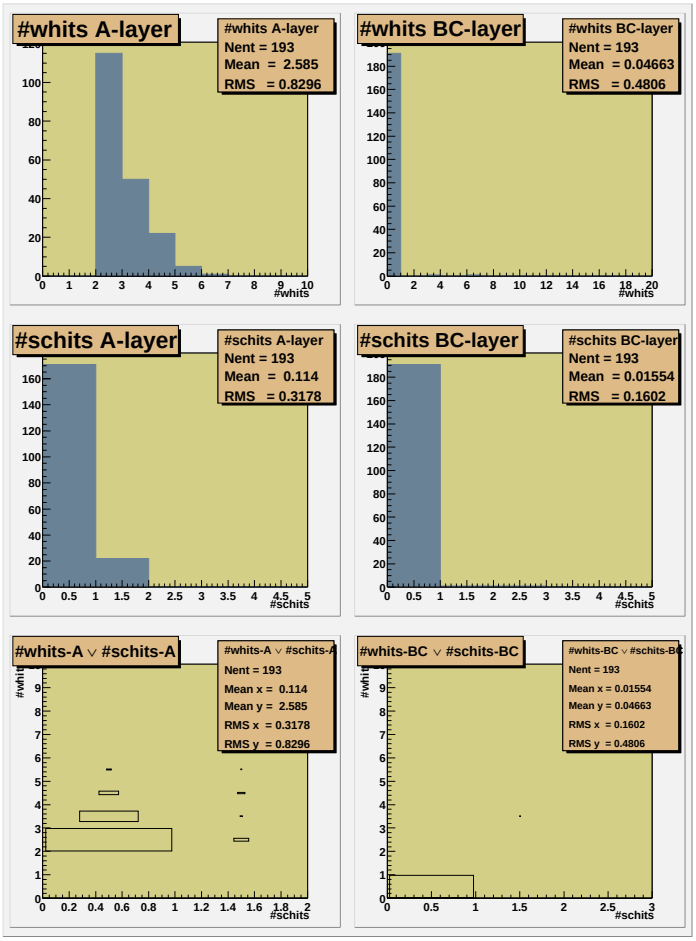

Figure 5: Distribution of hits for muon objects not passing the loose cut

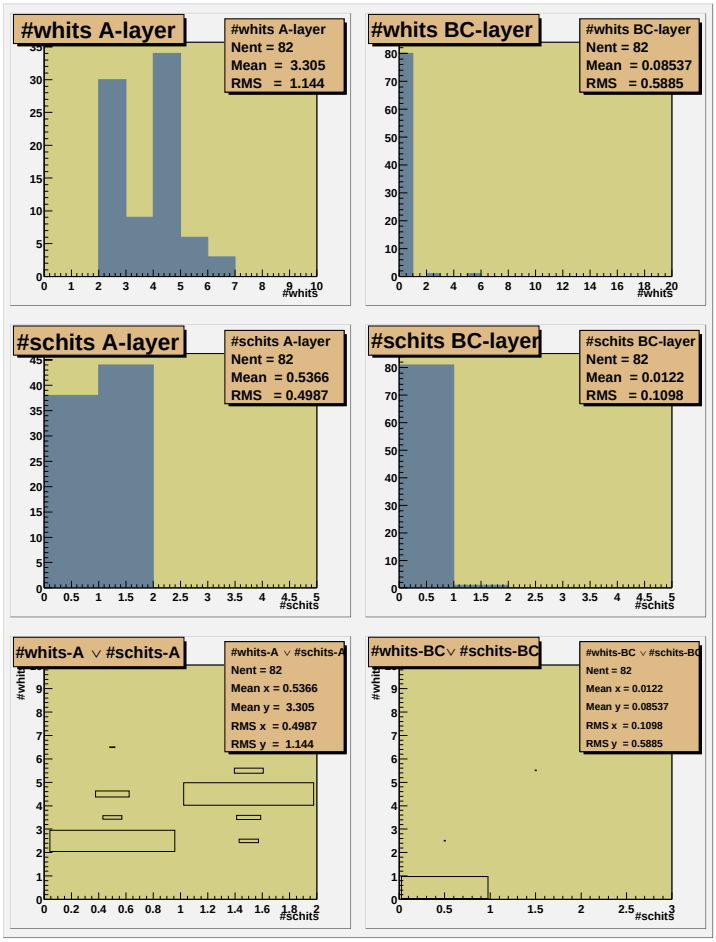

Figure 6: Distribution of hits for muon objects passing the loose cut

Based on these distributions, the Muon ID criteria for a loose muon in the muon system only are defined as:

- ≥ 3 wire hits in the A-layer, OR ≥ 2 wire hits AND ≥ 1 scintillator hit in the A-layer

Note, that an added requirement for a central track match has to be added later.

The number of hits for the Sample 2 is shown in Figure 7 for muon objects that have been defined as 'not passing the tight cut' and in Figure 8 for muon objects that have been defined as 'passing the tight cut'.

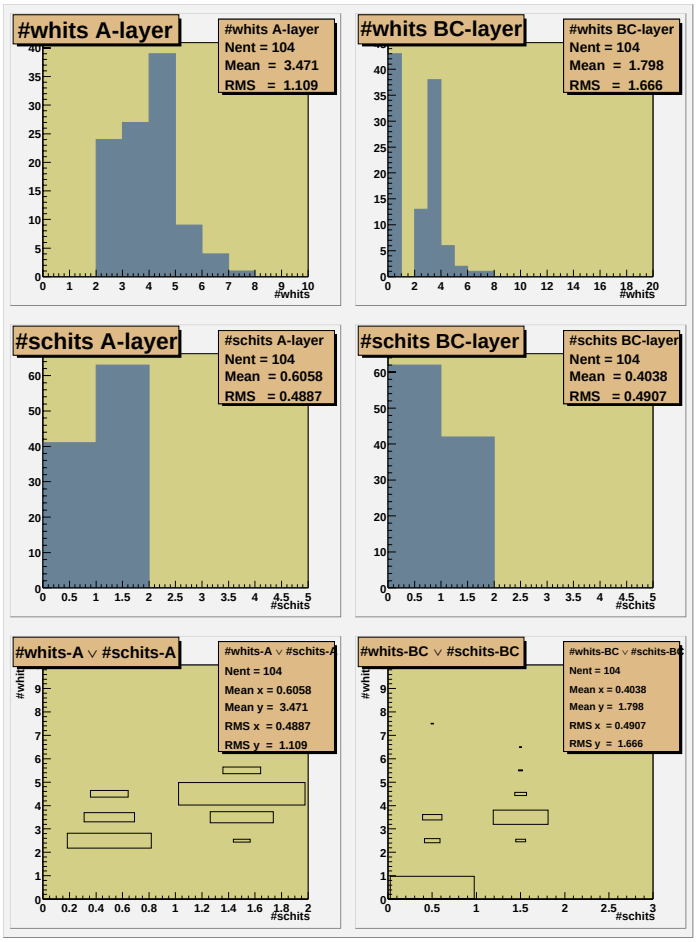

Figure 7: Distribution of hits for muon objects not passing the tight muon id cut

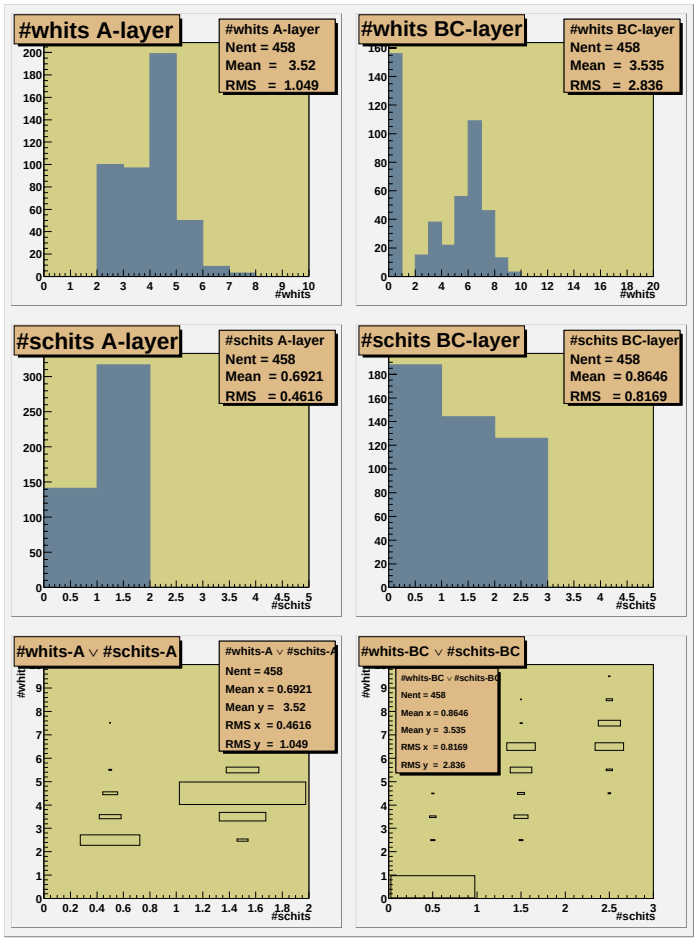

Figure 8: Distribution of hits for muon objects passing the tight muon id cut

Based on above distributions, the Muon ID criteria for a medium muon in the muon system only are defined as:

- ≥ 3 wire hits in the A-layer, OR ≥ 2 wire hits and ≥ 1 scintillator hit in the A-layer
- ≥ 1 scintillator hit in the B- or C-layer
- ≥ 2 wire hits in the B- or C-layer
- $\chi^2 \geq 0$

For a tight muon in the muon system only, these criteria are:

- ≥ 1 scintillator hit in the A-layer
- ≥ 2 wire hits in the A-layer
- ≥ 1 scintillator hit in the B- or C-layer
- ≥ 4 wire hits in the B- and C-layer
- $\chi^2 \geq 0$

Testing the Muon ID criteria on MC data

To get a feel for the efficiency of these ID definitions, a sample[2] of single muons is analyzed. This sample consists of 5000 single muons, generated with a flat p_T distribution between 5 and 100 GeV/c and 1.1 minimum bias overlaid. The efficiency of all three ID definitions is listed below.

Muon ID definition	Number of events
Number of events	5000
Number of reconstructed muon local track[3]	5723
Number of reconstructed muon local tracks passing loose Muon ID cuts	3987 (69.7%)
Number of reconstructed muon local tracks passing medium Muon ID cuts	2744 (47.9%)
Number of reconstructed muon local tracks passing tight Muon ID cuts	2499 (43.7%)

A handful of events not passing the cuts are viewed in the event display to make sure that no good muons are cut away. Some events are found that contain an A-segment muon, which should have passed the loose cut but did not. This is traced back to a bug in *muo_trackreco*, which causes some A-segments not to be upgraded to tracks. The bug has been reported to the authors of *muo_trackreco*. Furthermore, note that there was no association of the local muon track with a MC muon required.

Testing the Muon ID criteria on real data

To be sure that good tracks in the data are not thrown out unnecessarily, 3 samples of real data events are selected:

- A sample not passing the loose cut because the A-segment has one wire hit or one scintillator hit too few to pass the cut
- A sample not passing the medium cut due to having 1 less hit than required to pass the cut
- A sample not passing the tight cut due to having 1 less hit than required to pass the cut.

These three samples are then eye scanned in the d0ve display to search for muon tracks that should pass the appropriate cut. No such tracks are found.

Matching the muon local track with central tracks

A match of the local muon track with a track in the central tracker is a powerful indication that a muon is a real muon. Consequently, the definitions for Muon ID have to be adapted to reflect this. To investigate the quality of the match of a central track with a local track in the muon system, a sample of 200 events is selected from the data in which there is a tight muon present. Only tight muons are taken so that we are relatively sure that a muon was passing through the muon system, and the

[2] /prj_root/779/alg_7/mudata/d0sim_mu_mb1.1_t01.24

[3] The number of reconstructed muon local tracks is higher than 5000 because of the overlaid 1.1 minimum bias. Most of these muon tracks are A-segments only.

muon was probably not a background muon. This sample is reconstructed with d0reco version p10.08.01, in which the central track reconstruction has been fixed to deal with the offset vertex, and analyzed with the head of *muo_analyze*, in which the central track extrapolation is implemented. Each central track in the sample with an impulse greater than 2 GeV/c is extrapolated to the A-layer of the muon system, and the position, direction, p_T and charge of both tracks are compared. The results of this comparison are shown in Figure 9.

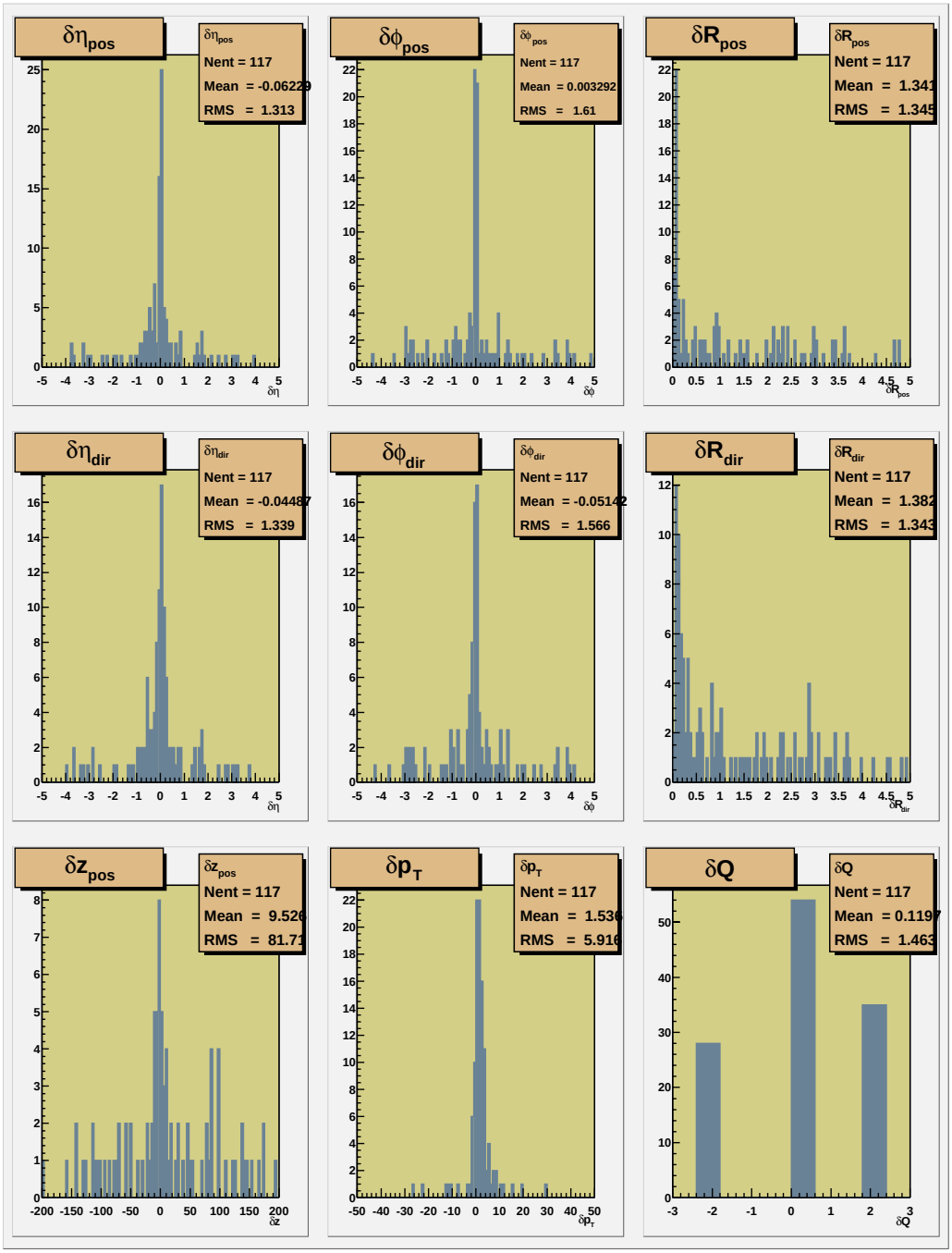

Figure 9: relation between the extrapolated central track and the local track in the muon system, measured at the A-layer of the muon system

Most of the central tracks used in this plot are SMT only tracks, since the CFT is only partly instrumented. Therefor, the resolution of these tracks is not as good as we can expect from future data. However, we can conclude some things from these plots:

- A match between a central track and a muon local track can be defined as $\delta R_{pos} < 0.4$
- The δz resolution seems to be quite poor. This can be attributed to a bad η direction measurement of the central track
- Due to the poor p_T resolution of the (current) central tracker, having a cut on the p_T does not seem feasible
- In half of the cases, the central tracker and the muon system disagree about the charge of the muon. Thus, for now the charge cannot be used to match a central track to a muon local track.

Concluding, a match between a central track and a muon local track is defined when the δR_{pos} between the extrapolated central track position at the A-layer, and the muon local track position at the A-layer is less than 0.4.

With this added requirement, the Muon ID definitions can be refined. First however, it is convenient to define some other ID objects:

- A-segment:
  - segment with ≥ 3 wire hits in the A-layer, or
  - segment with ≥ 2 wire hits in the A-layer and ≥ 1 scintillator hits in the A-layer
- B/C-segment (i.e. B or C segment):
  - segment with ≥ 2 wire hits and ≥ 1 scintillator hit in the B- or C- layer
- BC-segment:
  - segment with ≥ 4 wire hits and ≥ 1 scintillator hit in the B- or C-layer
- Central Track match:
  - δR_{pos}(central track, muon track) < 0.4

The first three definitions are extracted from the definitions of loose, medium and tight local muons, the last from the central track match study.

We can now redefine the Muon ID definitions:

- Loose muon:
  - A-segment with a Central Track Match
  - A-segment, matched with a B/C segment, $\chi^2 > 0$
- Medium muon:
  - A-segment, matched with a B/C segment, $\chi^2 > 0$ and with a Central Track match
  - A-segment, matched with a BC segment, $\chi^2 > 0$
- Tight muon:
  - A-segment, matched with a BC segment, $\chi^2 > 0$ and with a Central Track match

Note, that these ID definitions are extracted from real data taken before the October 2001 shutdown. Since not all detector elements were working optimally, some ID criteria could not be used, or only used to a limited extent. This analysis has to be redone with post-shutdown data to tighten down and finalize the ID criteria.